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OPTIMUM PROPORTIONS OF TRUSS-CORE AND WEB-CORE SANDWICH PLATES LOADED IN COMPRESSION

By Melvin S. Anderson

Langley Research Center
Langley Field, Va.

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SUMMARY

The proportions of truss-core and web-core sandwiches which give the minimum weight for carrying inplane compressive loads are presented. For lightly loaded sandwich plates, the truss-core sandwich is less efficient than a honeycomb sandwich, but for higher loading intensities, the truss-core sandwich is most efficient. The web-core sandwich is not as efficient as either the truss-core or honeycomb sandwich.

INTRODUCTION

Sandwich construction makes possible the fabrication of lightweight airframe components out of thin gages of high-density materials currently being considered for elevated temperature applications. The ideal sandwich would consist of two high-strength faces separated by a very light core material of adequate shear stiffness. In practice, this ideal is approached in a sandwich with a lightweight honeycomb core. Such a sandwich is usually fabricated by adhesive bonding, or by brazing if high-temperature service is required. Inasmuch as brazing has certain limitations, welding processes are also receiving attention as a method for mass producing large parts. Since the honeycomb sandwich is not easily fabricated by welding, other types of sandwiches which are more amenable to welding have been considered. Two of these configurations are shown in figure 1 and have been denoted as the single-truss-core and the double-truss-core sandwich. These two sandwiches along with a third configuration, the web-core sandwich, are studied in this paper.

The controlling factor in the design of sandwich plates is often the inplane compressive loading. Thus, the results of a weight-strength study of truss-core and web-core sandwich plates subject to inplane compressive loads would indicate sandwich proportions which in most cases could be considered the optimum proportions. Such an analysis is made in this paper, and the optimum proportions are determined as the proportions which lead to the least weight for a specified value of compressive load and plate width. For analysis purposes, the cross sections of these sandwiches have been idealized as shown in figure 2. The truss-core sandwiches have fairly high core densities and high values of transverse shear stiffness, while the web-core sandwich has somewhat lower core densities and very low values of transverse shear stiffness. These and other factors which affect the compressive buckling load of these configurations are investigated in order to find the optimum proportions. The weight efficiency at room temperature of these configurations is then compared with the efficiency of honeycomb construction and of solid plates of high-strength aluminum alloy.

SYMBOLS

b plate width

D_{Qx},D_{Qy} transverse shearing stiffness per unit length in x and y directions

E modulus of elasticity

E_t tangent modulus

E_s secant modulus

G shear modulus

h total thickness of sandwich

$\bar{I}$ average moment of inertia per unit width

k buckling-stress coefficient

P_i compressive load per unit width

r_x,r_y transverse shear stiffness parameters

t plate thickness

$\bar{t}$ cross-sectional area of sandwich plate per unit width, expressed as an equivalent thickness

w weight of sandwich per unit surface area

η plasticity reduction factor

θ angle between face-sheet element and core element

μ Poisson's ratio

ρ_c weight of core divided by volume between face sheets

ρ weight density of sandwich material

σ_{cr} buckling stress

σ_{cy} 0.2-percent-offset compressive yield stress

Subscripts:

c core

f face sheet

ANALYSIS

The weight-efficiency analysis used in the present investigation is similar to the analysis of reference 1, which was employed in a study of honeycomb sandwiches. The efficiency charts in reference 1 show $\rho\bar{t}/b$ (the weight per square inch of surface area per inch of width) plotted against P_i/b (an appropriate structural index). Inasmuch as testing experience shows that little increase in load is encountered after a sandwich plate buckles, the criterion for failure in sandwich plates is buckling.

The resistance of a sandwich to plate buckling is due primarily to the face sheets inasmuch as the face sheets contribute the major portion of the moment of inertia of the sandwich. The core then may be thought of as stabilizing the face sheets against plate buckling. For optimum design, the stabilization material should be the minimum amount of material that will give the necessary support to the face sheets. For the sandwiches shown in figure 2, the core has two stabilizing functions: (1) to provide adequate transverse shear stiffness, and (2) to prevent local buckling of the individual elements before overall plate instability. An efficient sandwich will have the lightest weight core that satisfactorily meets these requirements. The factors which affect the determination of the lightest core are different for the truss-core and web-core sandwiches and will be discussed separately in the following sections.

Efficiency of Truss-Core Sandwich Plates

Preliminary calculations indicated that changes in transverse shear stiffness caused by moderate changes in core thickness or in the angle between the core element and the face sheet produce very little change in the plate-buckling coefficient. However, such changes in core dimensions can cause appreciable changes in the local buckling stress. For that reason, the requirement that the local buckling stress be a maximum for a given core weight was chosen as the determining factor for optimum core proportions.

The local buckling stress for the truss-core sandwich can be obtained from reference 2. By using these results, proportions have been found which will yield the lightest core for a specified value of the local buckling stress and are shown in the form of carpet plots in figures 3 and 4. Values of θ and t_c/t_f corresponding to the least weight core are plotted as a function of h/t_f and the local-buckling stress which has been incorporated in the parameter $\sigma_{cr}/\eta E$, the so-called elastic critical strain. These proportions were calculated by selecting a value of h/t_f and core density; then θ and consequently t_c/t_f were varied until a maximum value of $\sigma_{cr}/\eta E$ was found. The optimum value of θ decreases with h/t_f and $\sigma_{cr}/\eta E$ until a value of 45° is reached; then, θ remains constant at 45° for any lower values of h/t_f or $\sigma_{cr}/\eta E$. Figures 3 and 4 apply to a sandwich of any material provided the core and face sheets have essentially the same material properties. Similar charts for sandwiches of two materials could be made by extending the calculations of reference 2.

A sandwich plate having the proportions given by a point from figures 3 or 4 and having a plate buckling stress corresponding to the value of $\sigma_{cr}/\eta E$ in the figure will be the lightest sandwich for that particular value of stress and h/t_f. Therefore, the procedure for calculating efficiency curves for truss-core sandwich plates is as follows: A local buckling stress is selected arbitrarily along with a value of h/t_f, and the corresponding proportions are determined from figures 3 or 4. The proportions of the sandwich plate are now completely determined except for the width, which may be found by varying b/h until a value of b/h is found which will yield a plate buckling stress equal to the local buckling stress. Details for calculating the plate buckling stress of both truss-core and web-core sandwiches are given in the appendix. A point on the efficiency chart (see figs. 5 or 6) is then obtained from the following equations:

$$\frac{P_i}{b} = \sigma_{cr} \frac{\bar{t}}{b} \tag{1}$$

$$\rho \frac{\bar{t}}{b} = \rho \frac{\bar{t}}{t_f} \frac{t_f}{h} \frac{h}{b} \tag{2}$$

The quantities on the right-hand side of equation (2) appear in the calculation of σ_{cr}. Repeating the above steps for different values of the local-buckling stress determines one curve on the efficiency plot. The efficiency curves thus obtained are shown in figure 5 for the single-truss-core sandwich and in figure 6 for the double-truss-core sandwich. The material properties used in the calculations are typical of a high-strength stainless steel (an elastic modulus of 30,000 ksi, a proportional limit of 130 ksi, and a yield stress of 180 ksi) and are the same as those used in reference 1. The buckling stress was never allowed to exceed the yield stress. Thus, the efficiency curves follow the line labeled $P_i/b = 180\bar{t}/b$ in the region of high loading intensity.

In certain applications, for example, to prevent local buckling in regions of concentrated loads, it may be desirable to have the local buckling stress higher than the plate buckling stress. Figures 3 and 4 are still applicable; the lightest weight sandwich for the desired local buckling stress may be determined directly from the figure.

Efficiency of Web-Core Sandwich Plates

The shear stiffness of the web-core sandwich is such that significant decreases in the buckling coefficient can occur as compared with a sandwich rigid in shear. Thus, as a first approximation, the local-buckling requirement may be neglected, and the requirement that the transverse shear stiffness D_{Qy} be a maximum for a given core weight can be used to determine the optimum proportions. An expression for the transverse shear stiffness D_{Qy} can be obtained from reference 3 as

$$\frac{D_{Qy}}{t_f} = \frac{2E}{\left(1 - \mu^2\right)} \left(\frac{t_f}{b_f}\right)^2 \frac{1}{2 \frac{t_f}{b_f}\left(\frac{h}{t_f} - 1\right)\left(\frac{t_f}{t_c}\right)^3 + 1} \tag{3}$$

The maximum value of D_{Qy} for a constant h/t_f and core density ratio $\rho_c/\rho = \left(t_c/t_f\right)\left(t_f/b_f\right)$ is obtained when the following equation is satisfied:

$$\frac{t_c}{t_f} = \sqrt[4]{2\left(\frac{h}{t_f} - 1\right)\frac{\rho_c}{\rho}} \tag{4}$$

For each value of ρ_c/ρ and h/t_f, t_c/t_f can be computed from equation (4), and an efficiency curve can be calculated by use of equations (1) and (2) which are applicable to both truss-core and web-core sandwich plates. Selecting one value of h/t_f and varying ρ_c/ρ will yield a family of efficiency curves as shown in figure 7. The lower envelope of these curves, which is the minimum-weight curve for that particular value of h/t_f, is essentially described by one value of ρ_c/ρ. Similar results were obtained for other values of h/t_f so that the optimum value of ρ_c/ρ can be determined as a function of h/t_f. This relationship is shown in figure 8 in which the optimum core density for a web-core sandwich is plotted against h/t_f. Also included is a curve showing the corresponding value of t_c/t_f calculated from equation (4). By using the proportions given in figure 8, efficiency curves for the web-core sandwich were calculated and are presented in figure 9.

The local buckling stress of web-core sandwiches with the proportions shown in figure 8 is quite high, well above the yield stress of structural materials except in the vicinity of $h/t_f = 20$. Thus, the requirement that the local buckling stress be greater than the plate buckling stress is satisfied except for web-core sandwiches designed to fail near the yield stress and having $h/t_f \approx 20$. For these particular proportions, slight modification of the proportions given in figure 8 will satisfy the local buckling requirement, but the effect of these modifications on efficiency will be negligible.

DISCUSSION

The buckling characteristics of the truss-core sandwiches proportioned according to the curves of figures 3 and 4 are of some interest. From the buckling charts of reference 2, it can be seen that most of the proportions given in figures 3 and 4 result in a sandwich that has the core less stable than the face sheets. That is, the proportions are such that the core tends to buckle while the face sheets are restraining the formation of buckles. On the other hand, overall plate buckling is resisted primarily by the face sheets of the sandwich inasmuch as the face sheets are responsible for most of the bending stiffness of a sandwich plate. It can be reasoned, therefore, that if the face sheets of a sandwich are stable as far as local buckling is concerned, the face sheets will provide the necessary plate stiffness so that the sandwich will sustain the theoretical plate-buckling stress. However, if the face sheets are unstable for local buckling, eccentricities might cause interaction between the two modes so that the sandwich will buckle prematurely. These observations have been confirmed experimentally on a few tests of truss-core sandwich plates. Thus, it is desirable that a sandwich be proportioned in such a manner that the core is primarily responsible for local buckling. The optimum properties given in figures 3 and 4 in general satisfy this requirement.

The curves in figures 5, 6, and 9 show that weight decreases as h/t_f increases. However, if h/t_f is increased further than shown in figures 5, 6, and 9, the curves would tend to cross each other or to be coincident with one another. Larger increases in h/t_f will actually show a weight penalty. Thus, the lower curves of figures 5, 6, and 9 represent the values of h/t_f which give essentially maximum efficiency. These lower envelope curves may be compared with curves for more conventional forms of construction to obtain a better idea of the weight of truss-core and web-core sandwich construction. In figure 10 the weight efficiency of web-core and truss-core sandwiches is compared with the efficiency of honeycomb sandwiches and flat plates of high-strength aluminum alloy. These latter curves were taken from reference 1. The curve for honeycomb construction is based on a core density of 9.6 lb/cu ft $\left(\rho_c/\rho = 0.02\right)$, but this density does not include the weight of bonding material.

The results presented in figure 10 indicate that honeycomb construction is the most efficient of those considered at lower values of P_i/b. In actuality this advantage is reduced somewhat because the weight of bonding material necessary to fabricate the honeycomb sandwich was not considered. The double-truss-core sandwich is slightly more efficient than the single-truss-core sandwich because the double-truss-core sandwich can have lower core densities for the deeper, more efficient sandwiches. However, in a comparison of the two configurations at identical values of h/t_f, the single-truss-core sandwich is more efficient when h/t_f is less than 20. (See figs. 5 and 6.) Because of low transverse shear stiffness, the web-core sandwich is less efficient than either truss-core sandwich. All of the steel sandwich configurations show a substantial weight saving over solid plates of high-strength aluminum alloy.

The actual sheet gages and sandwich dimensions that result from a typical design problem are best illustrated by a numerical example. Assume that an edge loading of 3 kips per inch must be sustained over a width of 10 inches. The dimensions of the lightest truss-core sandwich that will carry this loading may be found as follows: For this loading condition, P_i/b is equal to 0.3 and a double truss-core sandwich having a value of h/t_f equal to 40 will satisfy the design conditions (see fig. 6). The value of $\rho\bar{t}/b$ is read from figure 6 as 0.00077. In calculating $\rho\bar{t}/b$, a value of 0.278 lb/cu in. was used for the density of the material. Thus $\bar{t}/b$ can be computed as

$$\frac{\bar{t}}{b} = \frac{1}{\rho}\frac{\rho\bar{t}}{b} = \frac{0.00077}{0.278} = 0.00277$$

and

$$\bar{t} = \frac{\bar{t}}{b} b = (0.00277)10 = 0.0277$$

In order to determine θ and t_c/t_f, σ_{cr} must be known, and may be determined as follows:

$$\sigma_{cr} = \frac{P_i}{b}\frac{b}{\bar{t}} = \frac{0.3}{0.00277} = 108 \text{ ksi}$$

For this value of σ_{cr}, η equals unity and $\sigma_{cr}/\eta E$ is

$$\frac{\sigma_{cr}}{\eta E} = \frac{108}{(1)\ 30{,}000} = 0.0036$$

From figure 4 θ is determined as 50.2° and t_c/t_f is equal to 0.72. The face sheet thickness may now be determined by combining equations (A6) and (A8) of the appendix.

$$t_f = \frac{\bar{t}}{2 + \dfrac{2\dfrac{t_c}{t_f}\left(\dfrac{h}{t_f} - 2\right)}{\left(\dfrac{h}{t_f} - 1\right)\cos\theta}} = \frac{0.0277}{2 + \dfrac{2(0.72)(38)}{(39)(0.640)}} = 0.00662 \text{ in.}$$

The remaining dimensions of the sandwich are already determined as a function of t_f and may be readily computed as

$$t_c = \frac{t_c}{t_f} t_f = (0.72)(0.00662) = 0.00476 \text{ in.}$$

$$h = \frac{h}{t_f} t_f = 40(0.00662) = 0.265 \text{ in.}$$

The weight of the sandwich is

$$w = \rho(144)\bar{t} = (0.278)(144)(0.0277) = 1.11 \text{ lb/sq ft}$$

The use of large values of h/t_f is not always advisable inasmuch as this leads to thin face sheets which may not be desirable. (For example, a thin face sheet would be subject to puncture.) For the problem given in the preceding paragraph, the use of h/t_f equals 30 instead of 40 results in a small weight increase (less than 4 percent) but the face sheet thickness is increased nearly 25 percent over a sandwich having a value of h/t_f equals 40. The weight of the sandwich having the value of h/t_f equals 30 is 1.15 lb/sq ft and has the following dimensions:

$$t_c = 0.00456 \text{ in.}$$

$$t_f = 0.00815 \text{ in.}$$

$$h = 0.245 \text{ in.}$$

$$\theta = 45^\circ$$

A final comparison is made by giving the dimensions of a steel honeycomb sandwich designed for the same loading conditions used in the design problem of the preceding paragraphs. It is assumed that the material properties are the same as in the previous examples $\left(E = 30{,}000 \text{ ksi} \text{ and } \sigma_{cy} = 180 \text{ ksi}\right)$. With the use of the results of reference 1, the minimum weight honeycomb sandwich is found to have the following characteristics if the core density ratio is 0.02, the width 10 inches, and the compressive load 3 kips per inch:

$$t_f = 0.0087 \text{ in.}$$

$$h = 0.314 \text{ in.}$$

$$\sigma_{cr} = 172 \text{ ksi}$$

$$w = 0.948 \text{ lb/sq ft}$$

The weight of bonding or brazing material has not been included in the honeycomb sandwich. Such weights are generally from 0.2 to 0.3 lb/sq ft; thus the honeycomb sandwich would actually weigh about 1.2 lb/sq ft which is greater than the minimum weight truss-core sandwich. Note also that the honeycomb sandwich is stressed nearly to the yield value, while the stress in the truss-core sandwich is less than 60 percent of the yield stress of the material.

Weight is not the only factor in design and sometimes it is not even the most important consideration. Some other factors which may apply to the selection of a particular configuration are listed as follows:

(1) Inasmuch as a honeycomb core is nonload carrying, a higher stress is required to carry the same load as that carried by an equal weight web-core or truss-core sandwich. This effect is illustrated in the previous numerical example and is most significant at low values of P_i/b.

(2) Honeycomb sandwiches are known to be resistant to fatigue from noise and vibration loads. The effect of these loads on web-core and truss-core sandwiches has not been determined.

(3) As was noted in reference 4, honeycomb sandwiches are sensitive to concentrated loads which often necessitates the addition of rather heavy edge members and doubler plates. The weight of such reinforcements is generally less for truss-core sandwiches and web-core sandwiches because of their greater core strength.

(4) If it is necessary to circulate fluids through the structure to provide cooling, the longitudinal passages of the truss-core or web-core sandwich can be used for this purpose.

The choice of a sandwich configuration is not limited to those in figure 10. Several variations from the sandwiches discussed in this report are possible and some of these have been considered in other studies. However, the wide variation in core properties (core density and shear stiffness) represented by the honeycomb, truss-core, and web-core sandwich suggest that the weight of other sandwich configurations would not be appreciably lower than the honeycomb or truss-core sandwich or appreciably higher than the web-core sandwich.

CONCLUDING REMARKS

The optimum proportions for truss-core and web-core sandwiches have been determined using plate compressive efficiency as a basis. The results of the study indicate that the double-truss-core sandwich is slightly more efficient than the single-truss-core sandwich. At low values of the structural index, honeycomb sandwiches are more efficient than truss-core sandwiches but at higher values of the structural index the truss-core sandwich is most efficient. The web-core sandwich is not as efficient as either truss-core or honeycomb construction; however, it is a significant improvement over material in the flat sheet condition.

The optimum proportions for the truss-core sandwich are such that the core is the unstable element as far as local buckling is concerned. Truss-core sandwiches so proportioned have the advantage of minimizing interaction of local buckling and plate buckling. If such interaction did occur, the sandwich could have a significant reduction in strength.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., June 8, 1959.

APPENDIX

PLATE BUCKLING OF TRUSS-CORE AND WEB-CORE SANDWICHES

In order to calculate the plate buckling stress, the cross sections of the web-core and truss-core sandwiches have been idealized as shown in figure 2. The buckling theory of reference 5 is applicable, and an expression for plate buckling, which is similar to the usual plate-buckling formula, can be obtained from reference 5 as

$$\sigma_{cr} = \frac{k\pi^2 \eta E \bar{I}_f}{b^2 \bar{t}} \tag{A1}$$

which may be written in terms of certain nondimensional quantities as

$$\sigma_{cr} = k\pi^2 \eta E \frac{\bar{I}_f}{h^2 t_f} \frac{t_f}{\bar{t}} \left(\frac{h}{b}\right)^2 \tag{A2}$$

η is the plasticity reduction factor and was assumed to be the same as for a solid, simply supported plate. An expression for η, which also was used for local buckling of the plate elements as well as overall plate buckling, is given in reference 6 as

$$\eta = \frac{E_s}{E}\left(\frac{1}{2} + \frac{1}{2}\sqrt{\frac{1}{4} + \frac{3}{4}\frac{E_t}{E_s}}\right) \tag{A3}$$

$\bar{I}_f$ is the moment of inertia of the face sheets about the neutral axis, thus

$$\frac{\bar{I}_f}{h^2 t_f} = \frac{\left(\frac{h}{t_f}\right)^3 - \left(\frac{h}{t_f} - 2\right)^3}{12\left(\frac{h}{t_f}\right)^2} \tag{A4}$$

which may be approximated, except for small values of h/t_f, by

$$\frac{\bar{I}_f}{h^2 t_f} \approx \frac{\frac{1}{2}\left(\frac{h}{t_f} - 1\right)^2}{\left(\frac{h}{t_f}\right)^2} \tag{A5}$$

The quantity $\bar{t}/t_f$ is given by

$$\frac{\bar{t}}{t_f} = 2 + \frac{\rho_c}{\rho}\left(\frac{h}{t_f} - 2\right) \tag{A6}$$

where

$$\frac{\rho_c}{\rho} = \frac{t_c/t_f}{\left(\frac{h}{t_f} - 1\right)\cos\theta} \qquad \text{Single-truss} \tag{A7}$$

$$\frac{\rho_c}{\rho} = \frac{2\,\frac{t_c}{t_f}}{\left(\frac{h}{t_f} - 1\right)\cos\theta} \qquad \text{Double-truss} \tag{A8}$$

$$\frac{\rho_c}{\rho} = \frac{t_c/t_f}{b_f/t_f} \qquad \text{Web-core} \tag{A9}$$

The buckling coefficient k depends on the boundary conditions and the aspect ratio as in ordinary plate theory. For the present analysis, the unloaded edges are assumed to be simply supported, and the plate is assumed to be long in the loading direction. As used in reference 5, k is also a function of Poisson's ratio, the moment of inertia of the core relative to the face sheets, and the transverse shearing stiffness of the plate in both the longitudinal and transverse direction.

The quantities necessary to determine k are then as follows:

$$\frac{E\bar{I}_c}{E\bar{I}_f} = \frac{\frac{\rho_c}{\rho}\left(\frac{h}{t_f} - 2\right)^3}{\left(\frac{h}{t_f}\right)^3 - \left(\frac{h}{t_f} - 2\right)^3} \tag{A10}$$

or, by using the approximation given by equation (A5):

$$\frac{E\bar{I}_c}{E\bar{I}_f} \approx \frac{\frac{1}{6}\frac{\rho_c}{\rho}\left(\frac{h}{t_f} - 2\right)^3}{\left(\frac{h}{t_f} - 1\right)^2} \tag{A11}$$

The effect of shear deflections on the buckling coefficient k is determined from the parameters r_x and r_y which are given by:

$$r_x = \pi^2 E \frac{\bar{I}_f}{h^2 t_f}\left(\frac{h}{b}\right)^2 \frac{t_f}{D_{Qx}} \tag{A12}$$

$$r_y = \pi^2 E \frac{\bar{I}_f}{h^2 t_f}\left(\frac{h}{b}\right)^2 \frac{t_f}{D_{Qy}} \tag{A13}$$

The determination of k for a web-core sandwich is simplified inasmuch as D_{Qx} is many times greater than D_{Qy} and, as shown in reference 5, may be assumed to be infinite. The transverse shearing stiffness D_{Qx} can be obtained for the truss-core sandwich with the use of equation (E9) of reference 7 as:

$$\frac{D_{Qx}}{t_f} = G \frac{\rho_c}{\rho}\left(\sin^2\theta\right)\frac{\left(\frac{h}{t_f} - 1\right)^2}{\frac{h}{t_f} - 2} \tag{A14}$$

(If θ is 90° this expression also gives D_{Qx} for a web-core sandwich.) The expression for D_{Qy} of the web-core sandwich has been given in equation (3). The transverse shearing stiffness D_{Qy} of the truss-core sandwich can be obtained by assuming the core to consist of straight line elements, pin connected to the face sheets. Shear loads are then resisted by truss action, and D_{Qy} will be given by an expression similar to that given in reference 3 where D_{Qy} is denoted as P_d:

$$\frac{D_{Qy}}{t_f} = \frac{E}{1 - \mu^2} \frac{t_c}{t_f} \sin^2\theta \cos\theta \qquad \text{(single-truss)} \qquad (A15)$$

$$\frac{D_{Qy}}{t_f} = \frac{2E}{1 - \mu^2} \frac{t_c}{t_f} \sin^2\theta \cos\theta \qquad \text{(double-truss)} \qquad (A16)$$

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When the quantities given by equations (A10) to (A16) are known, k can be obtained from the equation or charts of reference 5.

In the fabrication of the core of a truss-core sandwich, the core elements will not be straight because the forming operation will produce a small radius of curvature near the line of attachment to the face sheet. This curvature will reduce the shear stiffness but may increase the local-buckling stress. For design purposes the shear stiffness obtained from a procedure such as given in reference 7 should be used; however, for an efficiency analysis, the small error caused by the use of equations (A15) and (A16) will only slightly affect the comparisons between truss-core sandwiches and other forms of construction.

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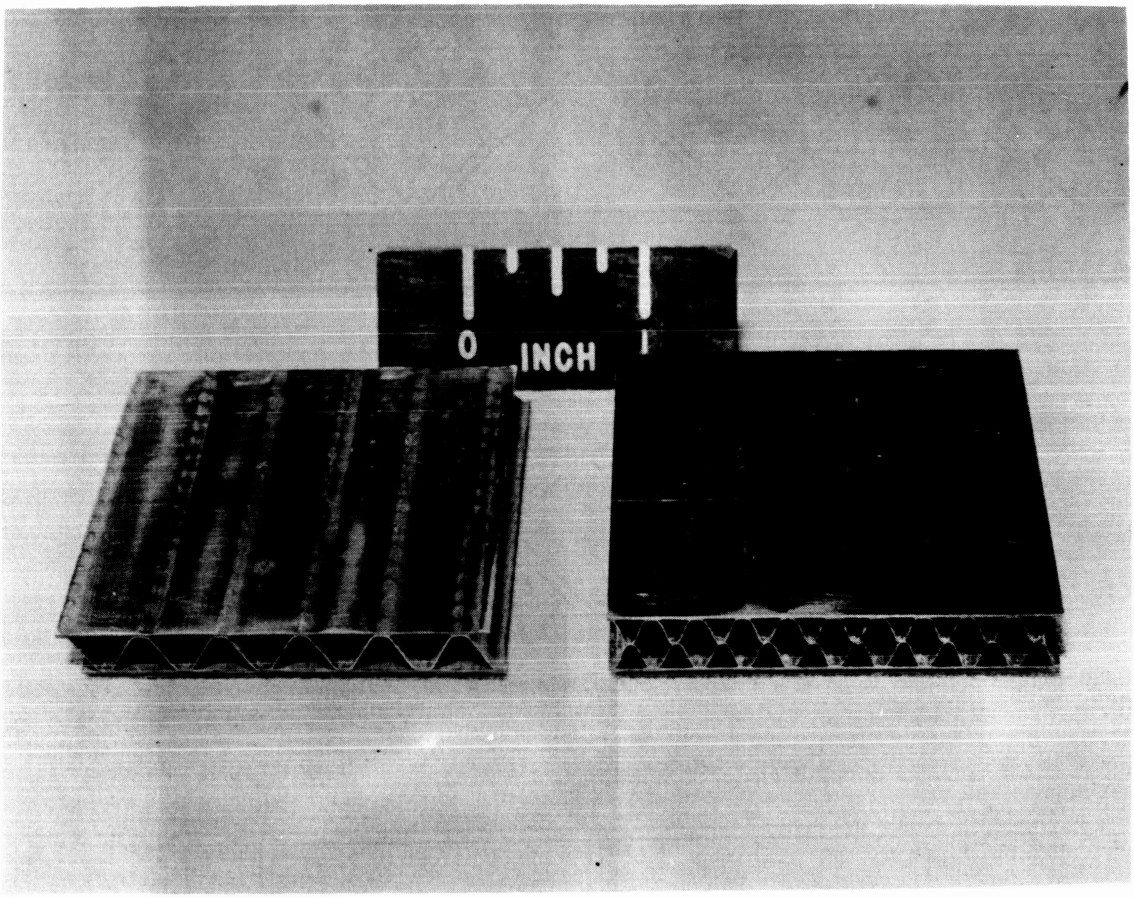
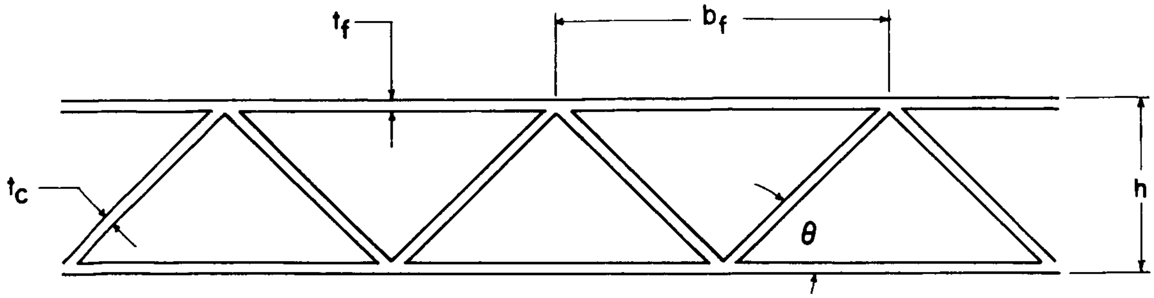
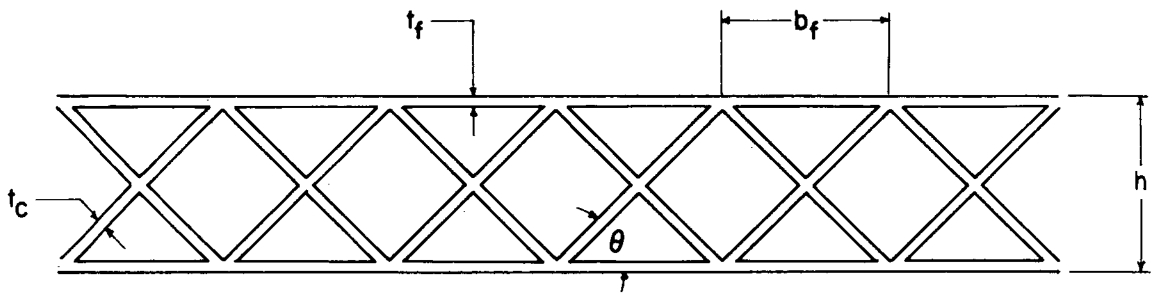


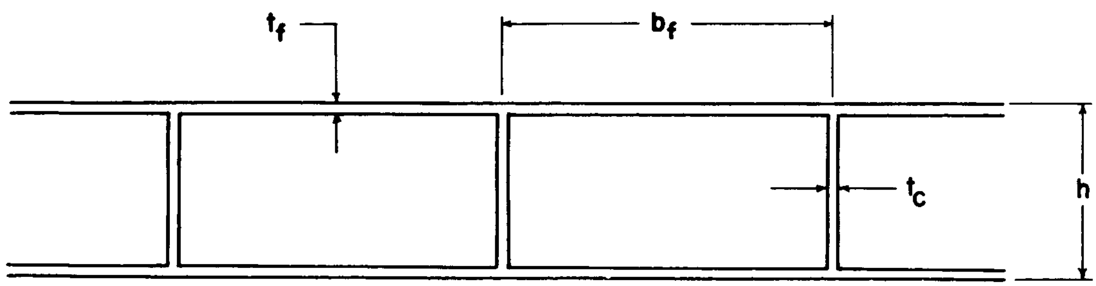
Figure 1.- Two truss-core sandwich configurations. L-58-1038



(a) Single truss.

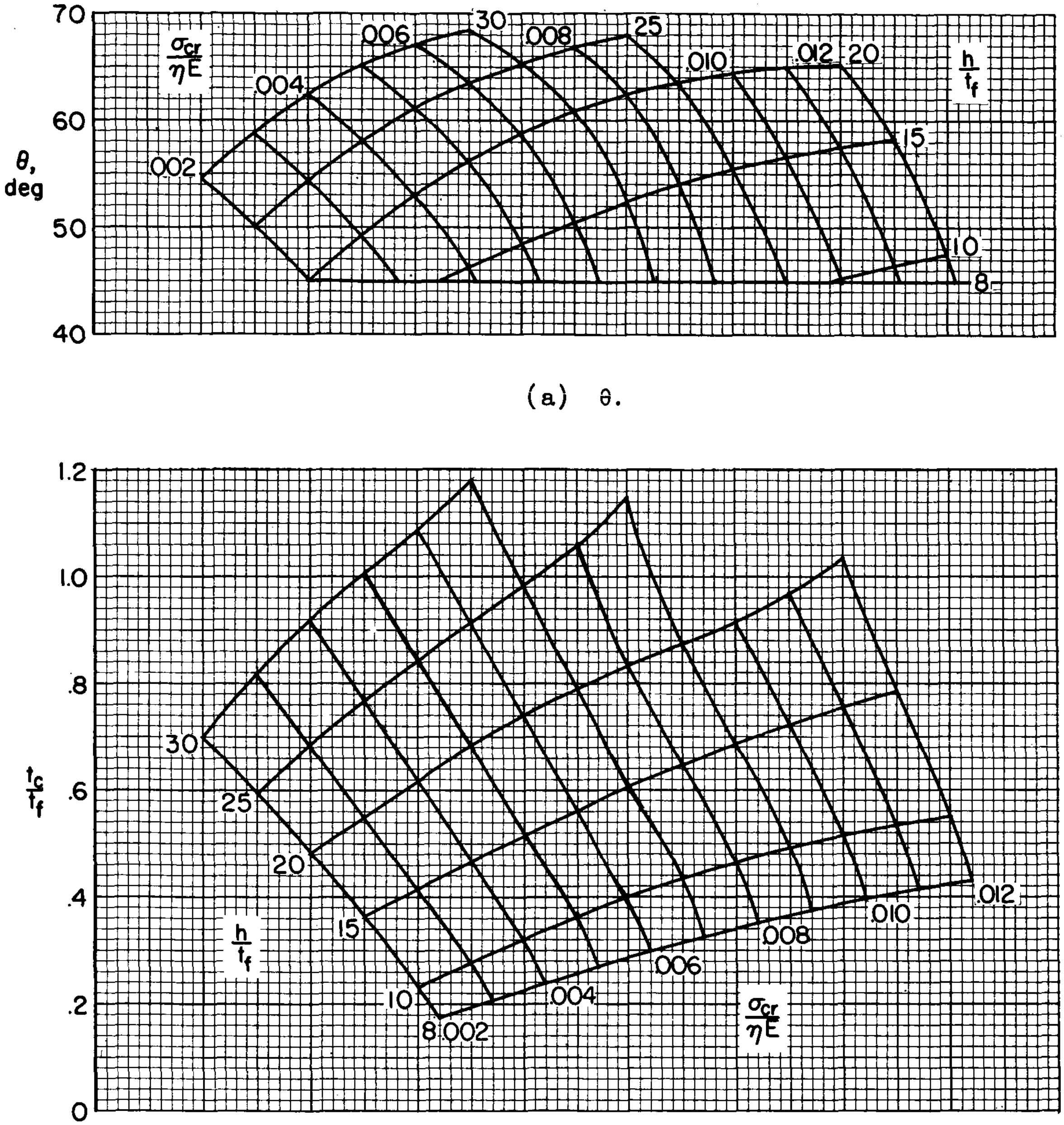


(b) Double truss.



(c) Web core.

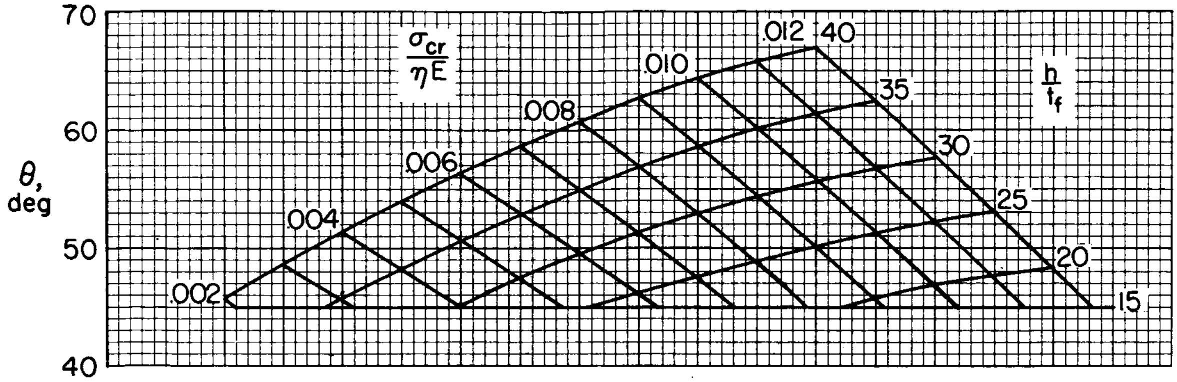
Figure 2.- Idealized cross section of truss-core and web-core sandwich plates.



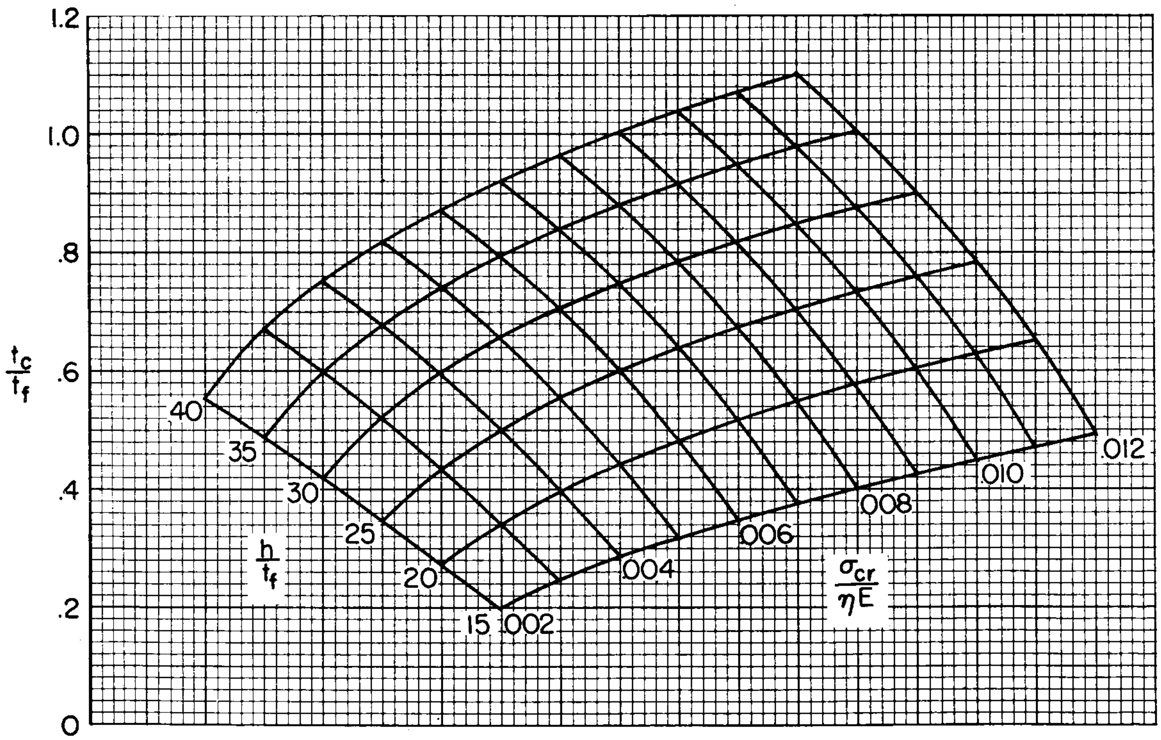
(a) θ.

(b) t_c/t_f.

Figure 3.- Optimum proportions of single-truss-core sandwiches.



(a) θ.



(b) t_c/t_f.

Figure 4.- Optimum proportions of double-truss-core sandwiches.

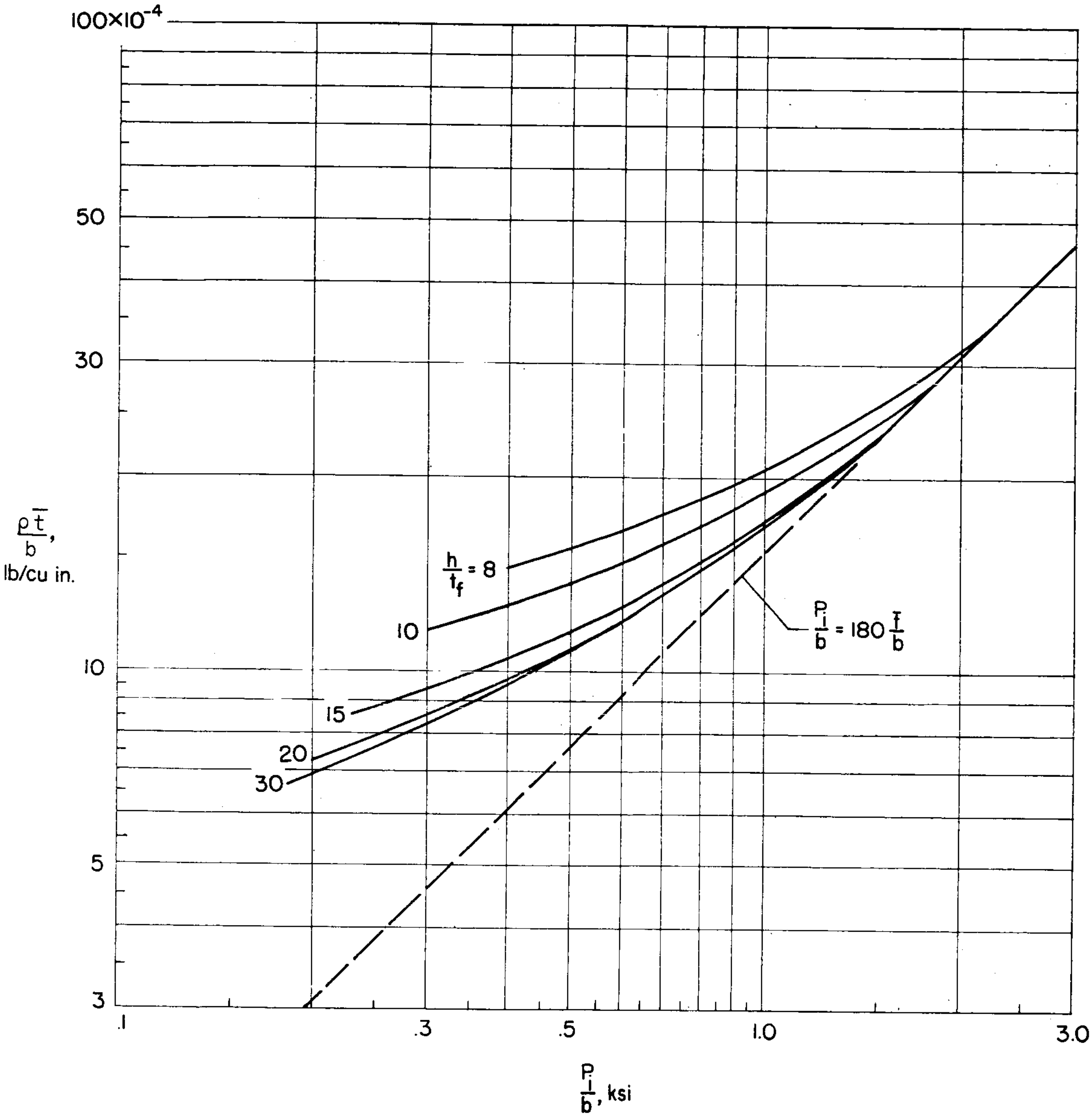


Figure 5.- Weight efficiency of stainless-steel single-truss-core sandwich.

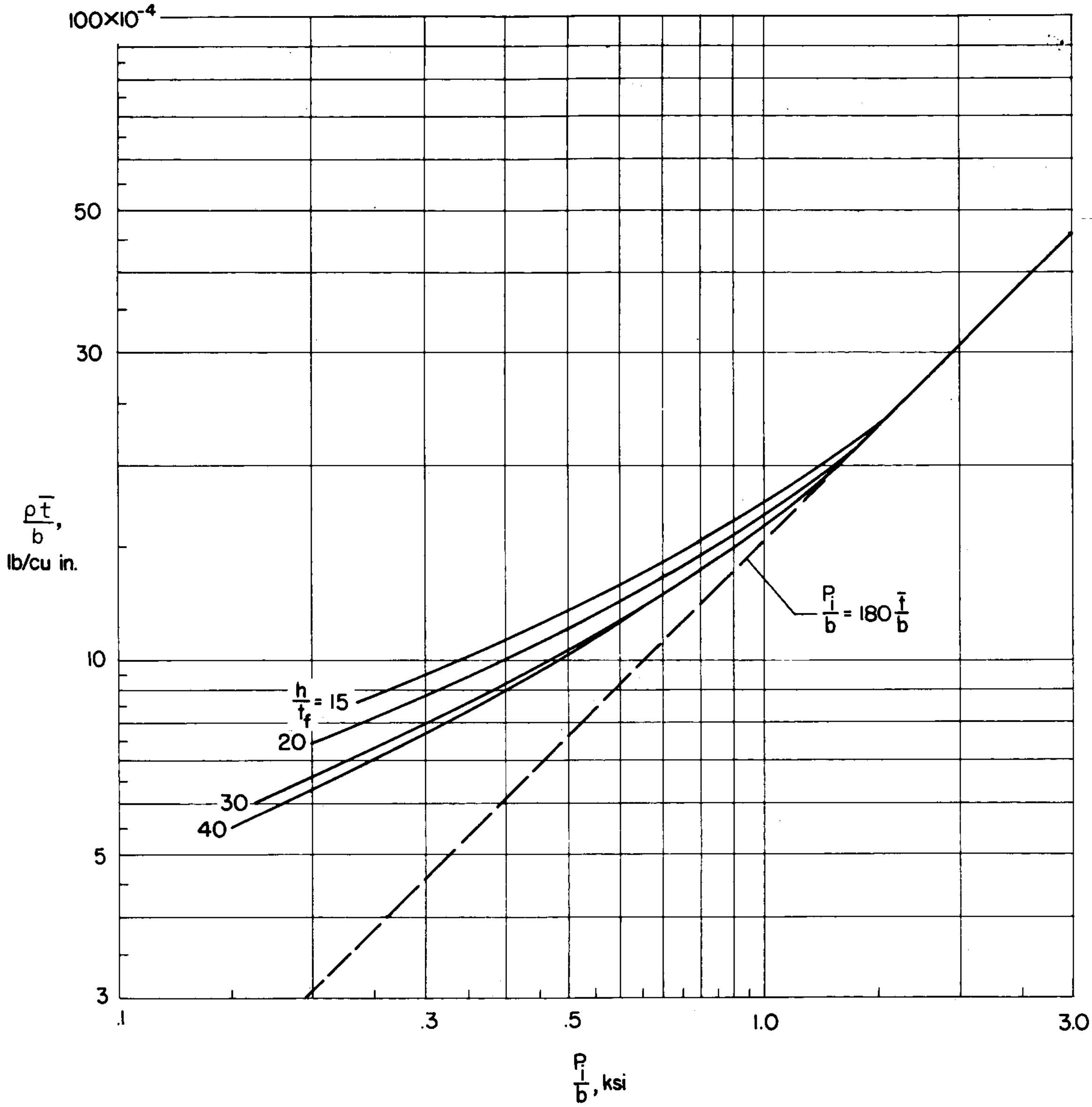


Figure 6.- Weight efficiency of stainless-steel double-truss-core sandwich.

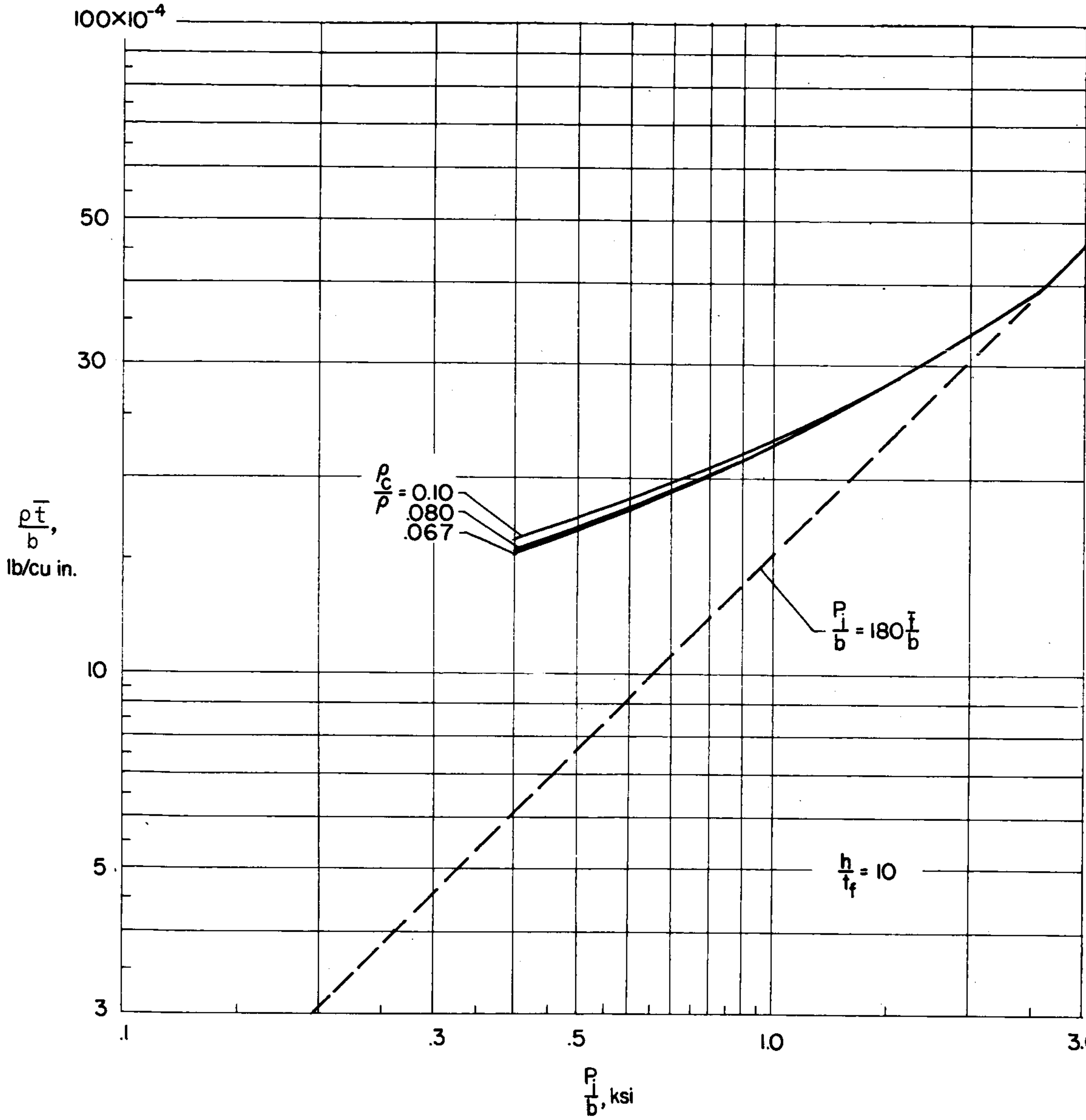


Figure 7.- Effect of core density on the efficiency of web-core sandwiches.

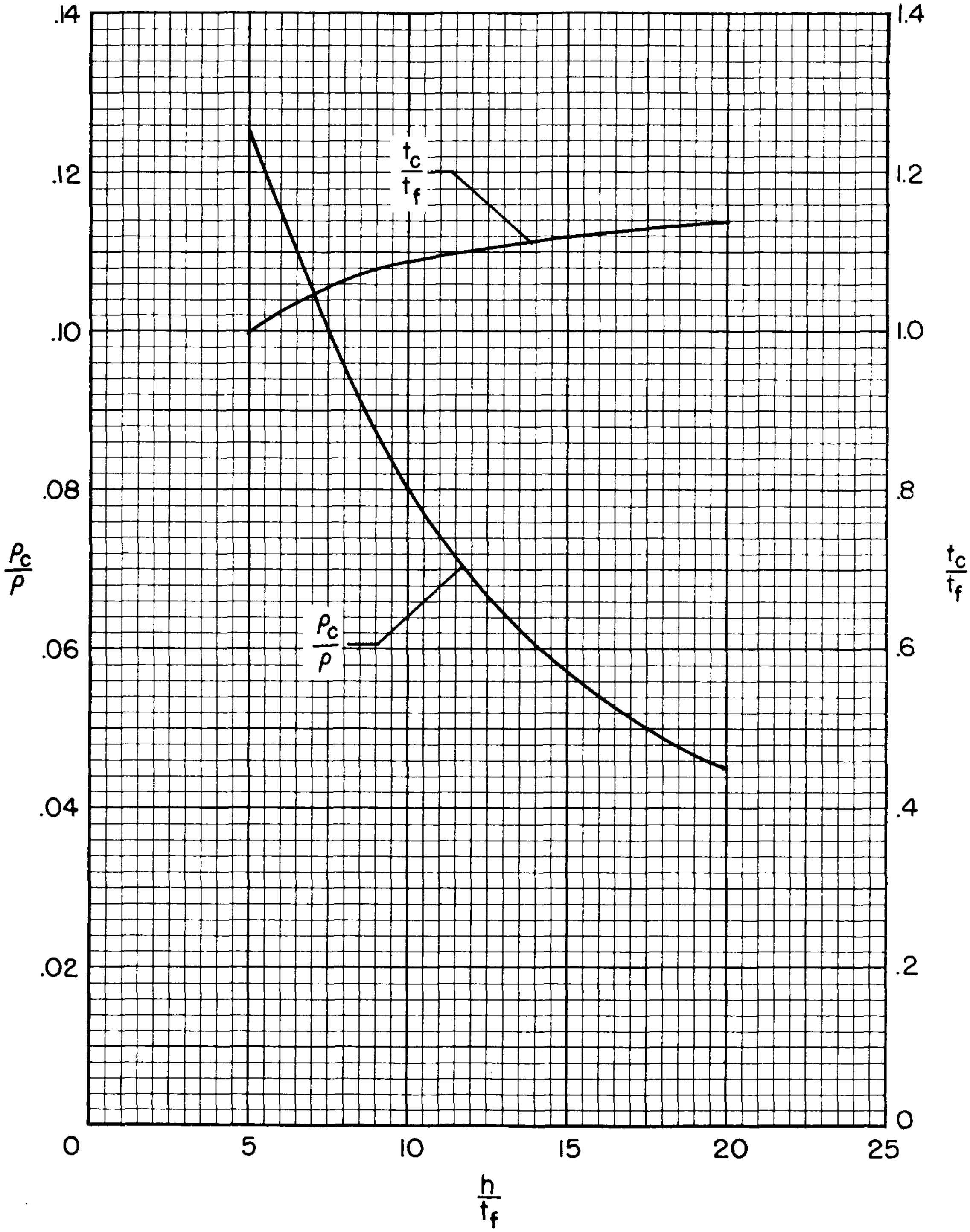


Figure 8.- Optimum core density and thickness ratio for web-core sandwiches.

4X

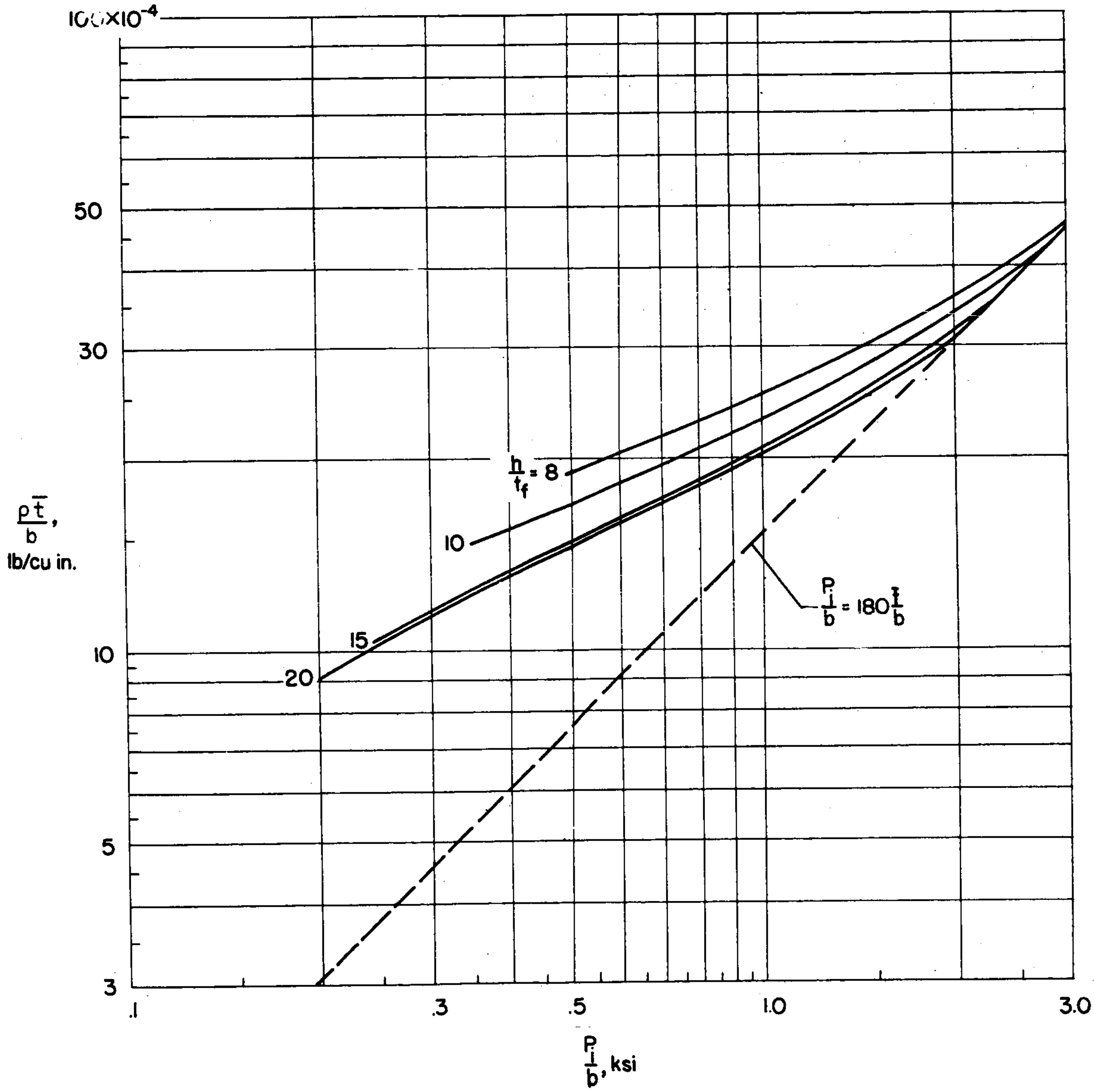


Figure 9.- Weight efficiency of stainless-steel web-core sandwich.

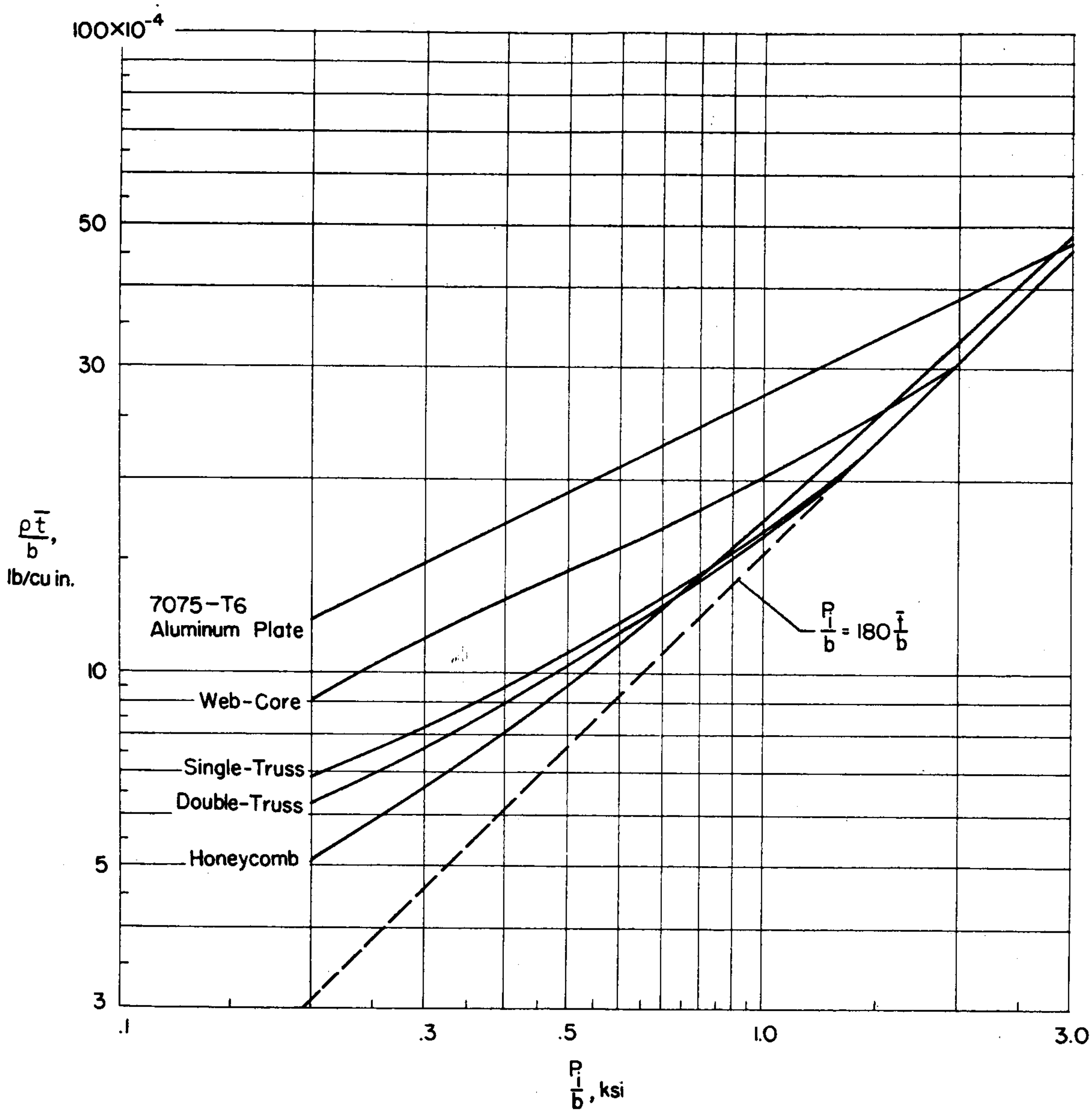


Figure 10.- Comparison of the plate compressive efficiency of v. configurations.